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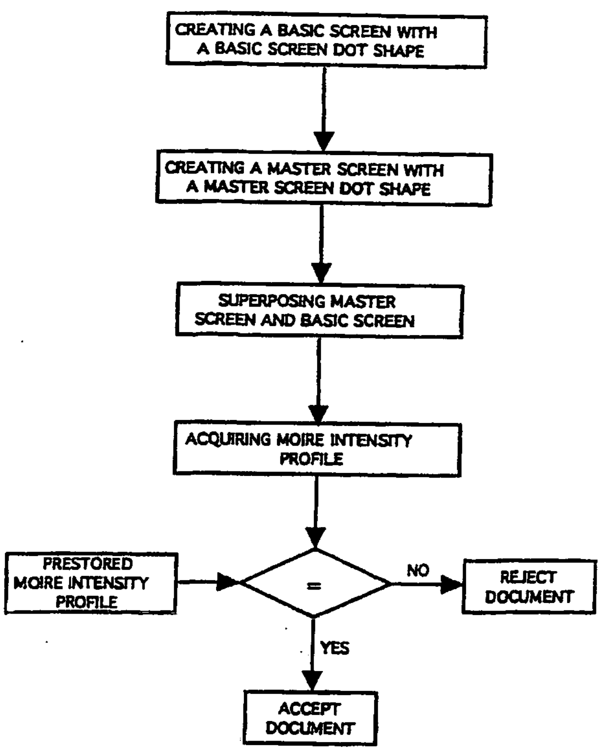
(54) Title: NEW METHODS AND APPARATUS FOR AUTHENTICATION OF DOCUMENTS BY USING THE INTENSITY PROFILE OF MOIRE PATTERNS



(57) Abstract: New methods and apparatus for authenticating security documents such as banknotes, passports, etc. which may be printed on any support, including transparent synthetic materials and traditional opaque materials such as paper. The invention is based on moire patterns occuring between superposed dot-screens. By using a specially designed basic screen and master screen, where at least the basic screen is comprised in the document, a moire intensity profile of a chosen shape becomes visible in their superposition, thereby allowing the authentication of the document. If a microlens array is used as a master screen, the document comprising the basic screen may be printed on an opaque reflective support, thereby enabling the visualization of the moire intensity profile by reflection. Different variants of the invention are disclosed, some of which are specially adapted for use as covert features. Automatic document authentication is supported by an apparatus comprising a master screen, an image acquisition means such as a CCD camera and a comparing processor whose task is to compare the acquired moire intensity profile with a prestored reference image. Depending on the match, the document handling device connected to the comparing processor accepts or rejects the document. An important advantage of the present invention is that it can be incorporated into the standard document printing process, so that it offers high security at the same cost as standard state of the art document production.

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eye and are intended for the general public, while other means are hidden and only detectable by the competent authorities, or by automatic devices. Some of the already used anti-counterfeit and authentication means include the use of special paper, special inks, watermarks, micro-letters, security threads, holograms, etc. Nevertheless, there is still an urgent need to introduce further security elements, which do not considerably increase the cost of the produced documents.

Moire effects have already been used in prior art for the authentication of documents. For example, United Kingdom Pat. No. 1,138,011 (Canadian Bank Note Company) discloses a method which relates to printing on the original document special elements which, when counterfeited by means of halftone reproduction, show a moire pattern of high contrast. Similar methods are also applied to the prevention of digital photocopying or digital scanning of documents (for example, U.S. Pat. No. 5,018,767 (Wicker), or U.K. Pat. Application No. 2,224,240 A (Kenrick & Jefferson)). In all these cases, the presence of moire patterns indicates that the document in question is counterfeit. However, in prior art no advantage is taken of the intentional generation of a moire pattern having a particular intensity profile, whose existence, and whose precise shape, are used as a means of authentifying the document. The only method known until now in which a moire effect is used to make visible an image encoded on the document (as described, for example, in the section "Background" of U.S. Pat. No. 5,396,559 (McGrew)) is based on the physical presence of that image on the document as a latent image, using the technique known as "phase modulation". In this technique, a uniform line grating or a uniform random screen of dots is printed on the document, but within the pre-defined borders of the latent image on the document the same line grating (or respectively, the same random dot-screen) is printed in a different phase, or possibly in a different orientation. For a layman, the latent image thus printed on the document is hard to distinguish from its background; but when a reference transparency consisting of an identical, but unmodulated, line grating (respectively, random dot-screen) is superposed on the document, thereby generating a moire effect, the latent image pre-designed on the document becomes clearly visible, since within its pre-defined borders the moire effect appears in a different phase than in the background. However, this previously known method has the major flaw of being simple to simulate, since the form of the latent image is physically present on the document and only filled by a different texture. The existence of such a latent image on the document

designed in accordance with the present disclosure, there appears in the superposition a highly visible repetitive moire pattern of a predefined intensity profile shape. For example, the repetitive moire pattern may consist of any predefined letters, digits or any other preferred symbols (such as the country emblem, the currency, etc.).

As disclosed in U.S. Pat. No. 5,275,870 (Halope et al.) it may be advantageous in the manufacture of long lasting documents or documents which must withstand highly adverse handling to replace paper by synthetic material. Transparent sheets of synthetic materials have been successfully introduced for printing banknotes (for example, Australian banknotes of 5 or 10 Australian Dollars).

The present invention concerns a new method for authenticating documents which may be printed on various supports, including (but not limited to) such transparent synthetic materials. In one embodiment of the present invention, the moire intensity profile shapes can be visualized by superposing a basic screen and a master screen which are both printed on two different areas of the same document (banknote, etc.). In a second embodiment of the present invention, only the basic screen appears on the document itself, and the master screen is superposed on it by the human operator or the apparatus which visually or optically validates the authenticity of the document. In a third embodiment of this invention, the master screen is a sheet of microlenses (hereinafter: "microlens array"). An advantage of this third embodiment is that it applies equally well to both transparent support, where the moire is observed by transmittance, and to opaque support, where the moire is observed by reflection. (The term "opaque support" as employed in the present disclosure also includes the case of transparent materials which have been made opaque by an inking process or by a photographic or any other process.)

The fact that moire effects generated between superposed dot-screens are very sensitive to any microscopic variations in the screened layers makes any document protected according to the present invention practically impossible to counterfeit, and serves as a means to distinguish easily between a real document and a falsified one.

41, 1994, pp. 1837–1862 (hereinafter, "Amidror94") and "Artistic Screening" by Victor Ostromoukhov and Roger D. Hersch, SIGGRAPH Conference 1995, pp. 219–228, have certain information and content which may relate to the present invention and aid in understanding thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be further described, by way of example only, with reference to the accompanying figures, in which:

FIGS. 1A and 1B show two line-gratings;

FIG. 1C shows the superposition of the two line-gratings of FIGS. 1A and 1B, where the (1,-1)-moire is clearly seen;

FIGS. 1D and 1E show the spectra of the line-gratings of FIGS. 1A and 1B, respectively;

FIG. 1F shows the spectrum of the superposition, which is the convolution of the spectra of FIGS. 1D and 1E;

FIG. 1G shows the intensity profile of the (1,-1)-moire of FIG. 1C;

FIG. 1H shows the spectrum of the isolated (1,-1)-moire comb after its extraction from the spectrum of the superposition;

FIGS. 2A, 2B and 2C show the spectrum of the superposition of two dot-screens with identical frequencies, and with angle differences of 30 degrees (in FIG. 2A), 34.5 degrees (in FIG. 2B) and 5 degrees (in FIG. 2C);

FIG. 3 shows the moire intensity profiles obtained in the superposition of a dot-screen comprising circular black dots of varying sizes and a dot-screen comprising triangular black dots of varying sizes;

FIG. 4 shows the moire intensity profiles obtained in the superposition of two dot-screens comprising circular black dots of varying sizes and a dot-screen comprising black dots of varying sizes having the shape of the digit "1";

FIGS. 12B, 12C and 12D show how missing sub-elements can render the letter of FIG. 12A unintelligible;

FIGS. 12E and 12F show how shifting of sub-elements can render the letter of FIG. 12A unintelligible;

FIG. 13 shows a magnified example illustrating how the irregular sub-element alterations method can render the basic screen of FIG. 11A unintelligible;

FIG. 14A is a schematic, magnified view of a small portion of a multicolor basic screen with triangular screen dots, where each of the screen dots is subdivided into three sub-elements of different colors;

FIG. 14B shows the dither matrix used to generate the magenta part of the multichromatic basic screen of FIG. 14A;

FIG. 14C shows the dither matrix used to generate the black part of the multichromatic basic screen of FIG. 14A;

FIG. 15A schematically shows a prestored moire intensity profile, its periods and its orientations;

FIG. 15B schematically shows an acquired moire intensity profile with its rotation angle error δ;

FIG. 15C schematically shows the intensity signals obtained when intersecting an acquired moire intensity profile by straight lines; and

FIGS. 16A and 16B show multichromatic variants of FIG. 12A and FIG. 12B, respectively.

FIG. 17 illustrates a block diagram with the steps of methods of the invention summarized therein.

DETAILED DESCRIPTION

The present invention is based on the intensity profiles of the moire patterns which occur in the superposition of dot-screens. The explanation of these moire intensity

consists of a 1D "comb" of impulses through the origin; in the case of a 2-fold periodic image the spectrum is a 2D "nailbed" of impulses through the origin.

Each impulse in the 2D spectrum is characterized by three main properties: its label (which is its index in the Fourier series development); its geometric location in the spectrum plane (which is called: "the impulse location"), and its amplitude. To the geometric location of any impulse is attached a frequency vector **f** in the spectrum plane, which connects the spectrum origin with the geometric location of the impulse. In terms of the original image, the geometric location of an impulse in the spectrum determines the frequency and the direction of the corresponding periodic component in the image, and the amplitude of the impulse represents the intensity of that periodic component in the image.

The question of whether or not an impulse in the spectrum represents a visible periodic component in the image strongly depends on properties of the human visual system. The fact that the eye cannot distinguish fine details above a certain frequency (i.e. below a certain period) suggests that the human visual system model includes a low-pass filtering stage. When the frequencies of the original image elements are beyond the limit of frequency visibility, the eye can no longer see them; but if a strong enough impulse in the spectrum of the image superposition falls closer to the spectrum origin, then a moire effect becomes visible in the superposed image.

According to the Convolution theorem (Eqs. (1), (2)), when m line-gratings are superposed in the image domain, the resulting spectrum is the convolution of their individual spectra. This convolution of combs (or nailbeds) can be seen as an operation in which frequency vectors from the individual spectra are added vectorially, while the corresponding impulse amplitudes are multiplied. More precisely, each impulse in the spectrum-convolution is generated during the convolution process by the contribution of one impulse from each individual spectrum: its location is given by the sum of their frequency vectors, and its amplitude is given by the product of their amplitudes. This enables us to introduce an indexing method for denoting each of the impulses of the spectrum-convolution in a unique, unambiguous way. The general impulse in the spectrum-convolution will be denoted the "$(k_1,k_2,\ldots,k_m)$-impulse," where m is the number of superposed gratings, and each integer k_i is the index (harmonic), within the comb (the

Therefore, the frequency, the period and the angle of the $(k_1,k_2,\dots,k_m)$-impulse (and of the $(k_1,k_2,\dots,k_m)$-moire it represents) are given by the length and the direction of the vector $\mathbf{f}_{k_1,k_2,\dots,k_m}$, as follows:

$$f = \sqrt{f_u^2 + f_v^2} \qquad T = 1/f \qquad \varphi = \arctan(f_v / f_u) \tag{6}$$

Note that in the special case of the (1,-1)-moire between m=2 gratings, where a moire effect occurs due to the vectorial sum of the frequency vectors $\mathbf{f}_1$ and $-\mathbf{f}_2$, these formulas are reduced to the well-known formulas of the period and angle of the moire effect between two gratings:

$$T_M = \frac{T_1 T_2}{\sqrt{T_1^2 + T_2^2 - 2T_1T_2\cos\alpha}} \qquad \sin\varphi_M = \frac{T_1 \sin\alpha}{\sqrt{T_1^2 + T_2^2 - 2T_1T_2\cos\alpha}} \tag{7}$$

(where T_1 and T_2 are the periods of the two original gratings and α is the angle difference between them, $\theta_2-\theta_1$). When $T_1=T_2$ this is further simplified into the well-known formulas:

$$T_M = \frac{T}{2\sin(\alpha/2)} \qquad \varphi_M = 90° - \alpha/2 \tag{8}$$

The moire patterns obtained in the superposition of periodic structures can be described at two different levels. The first, basic level only deals with geometric properties within the (x,y)-plane, such as the periods and angles of the original images and of their moire patterns. The second level also takes into account the amplitude properties, which can be added on top of the planar 2D descriptions of the original structures or their moire patterns as a third dimension, $z=g(x,y)$, showing their intensities or gray-level values. (In terms of the spectral domain, the first level only considers the impulse locations (or frequency vectors) within the (u,v)-plane, while the second level also considers the amplitudes of the impulses.) This 3D representation of the shape and the intensity variations of the moire pattern is called "the moire intensity profile".

The present disclosure is based on the analysis, using the Fourier approach, of the intensity profiles of moire patterns which are obtained in the superposition of periodic layers such as line-gratings, dot-screens, etc. This analysis is described in the following section for the simple case of line-grating superpositions, and then, in the next section, for the more complex case of dot-screen superpositions.

Result 1: The impulse amplitudes of the moire-comb in the spectrum-convolution are determined by a simple term-by-term multiplication of the combs of the original superposed gratings (or subcombs thereof, in case of higher order moires).

For example, in the case of a (1,-1)-moire (as in FIG. 1F) the amplitudes of the moire-comb impulses are given by: $c_n = a_{n,-n} = a^{(1)}{}_n\, a^{(2)}{}_{-n}$.

However, this term-by-term multiplication of the original combs (i.e. the term-by-term product of the Fourier series of the two original gratings) can be interpreted according to a theorem, which is the equivalent of the Convolution theorem in the case of periodic functions, and which is known in the art as the T-convolution theorem (see "Fourier theorems" by Champeney, 1987, p. 166; "Trigonometric Series Vol. 1" by Zygmund, 1968, p. 36):

***T*-convolution theorem:** Let $f(x)$ and $g(x)$ be functions of period T integrable on a one-period interval $(0,T)$, and let $\{F_n\}$ and $\{G_n\}$ (for $n = 0, \pm1, \pm2, \ldots$) be their Fourier series coefficients. Then the function:

$$h(x) = \tfrac{1}{T}\int_T f(x-x')\, g(x')\, dx' \tag{9}$$

(where $\int_T$ means integration over a one-period interval), which is called "the T-convolution of f and g" and denoted by "$f{*}g$," is also periodic with the same period T and has Fourier series coefficients $\{H_n\}$ given by: $H_n = F_n G_n$ for all integers n.

The T-convolution theorem can be rephrased in a more illustrative way as follows: If the spectrum of $f(x)$ is a comb with fundamental frequency of $1/T$ and impulse amplitudes $\{F_n\}$, and the spectrum of $g(x)$ is a comb with the same fundamental frequency and impulse amplitudes $\{G_n\}$, then the spectrum of the T-convolution $f{*}g$ is a comb with the same fundamental frequency and with impulse amplitudes of $\{F_nG_n\}$. In other words, the spectrum of the T-convolution of the two periodic images is the product of the combs in their respective spectra.

Using this theorem, the fact that the comb of the (1,-1)-moire in the spectral domain is the term-by-term product of the combs of the two original gratings (Result 1) can be interpreted back in the image domain as follows:

Moires between superposed dot-screens

The moire extraction process described above for the superposition of line-gratings can be generalized to the superposition of doubly periodic dot-screens, where the moire effect obtained in the superposition is really of a 2D nature:

Let $f(x,y)$ be a doubly periodic image (for example, $f(x,y)$ may be a dot-screen which is periodic in two orthogonal directions, θ_1 and $\theta_1 + 90°$, with an identical period T_1 in both directions). Its spectrum $F(u,v)$ is a nailbed whose impulses are located on a lattice $L_1(u,v)$, rotated by the same angle θ_1 and with period of $1/T_1$; the amplitude of a general (k_1,k_2)-impulse in this nailbed is given by the coefficient of the (k_1,k_2)-harmonic term in the 2D Fourier series development of the periodic function $f(x,y)$.

The lattice $L_1(u,v)$ can be seen as the 2D support of the nailbed $F(u,v)$ on the plane of the spectrum, i.e. the set of all the nailbed impulse-locations. Its unit points (0,1) and (1,0) are situated in the spectrum at the geometric locations of the two perpendicular fundamental impulses of the nailbed $F(u,v)$, whose frequency vectors are $\mathbf{f}_1$ and $\mathbf{f}_2$. Therefore the location $\mathbf{w}_1$ in the spectrum of a general point (k_1,k_2) of this lattice is given by a linear combination of $\mathbf{f}_1$ and $\mathbf{f}_2$ with the integer coefficients k_1 and k_2; and the location $\mathbf{w}_2$ of the perpendicular point $(-k_2,k_1)$ on the lattice can also be expressed in a similar way:

$$\begin{aligned} \mathbf{w}_1 &= k_1\mathbf{f}_1 + k_2\mathbf{f}_2 \\ \mathbf{w}_2 &= -k_2\mathbf{f}_1 + k_1\mathbf{f}_2 \end{aligned} \tag{10}$$

Let $g(x,y)$ be a second doubly periodic image, for example a dot-screen whose periods in the two orthogonal directions θ_2 and $\theta_2 + 90°$ are T_2. Again, its spectrum $G(u,v)$ is a nailbed whose support is a lattice $L_2(u,v)$, rotated by θ_2 and with a period of $1/T_2$. The unit points (0,1) and (1,0) of the lattice $L_2(u,v)$ are situated in the spectrum at the geometric locations of the frequency vectors $\mathbf{f}_3$ and $\mathbf{f}_4$ of the two perpendicular fundamental impulses of the nailbed $G(u,v)$. Therefore the location $\mathbf{w}_3$ of a general point (k_3,k_4) of this lattice and the location $\mathbf{w}_4$ of its perpendicular twin $(-k_4,k_3)$ are given by:

$$\begin{aligned} \mathbf{w}_3 &= k_3\mathbf{f}_3 + k_4\mathbf{f}_4 \\ \mathbf{w}_4 &= -k_4\mathbf{f}_3 + k_3\mathbf{f}_4 \end{aligned} \tag{11}$$

2D Fourier series development of the intensity profile of the (k_1,k_2,k_3,k_4)-moire; in other words, the amplitude of the (i,j)-th impulse of the cluster is the coefficient of the (i,j)-harmonic term in the Fourier series development of the moire intensity profile. By taking the inverse 2D Fourier transform of this extracted cluster we can analytically reconstruct in the image domain the intensity profile of this moire. If we denote the intensity profile of the (k_1,k_2,k_3,k_4)-moire between the superposed images $f(x,y)$ and $g(x,y)$ by "$m_{k_1,k_2,k_3,k_4}(x,y)$," we therefore have:

$$m_{k_1,k_2,k_3,k_4}(x,y) = \mathcal{F}^{-1}[M_{k_1,k_2,k_3,k_4}(u,v)] \tag{12}$$

The intensity profile of the (k_1,k_2,k_3,k_4)-moire between the superposed images $f(x,y)$ and $g(x,y)$ is therefore a function $m_{k_1,k_2,k_3,k_4}(x,y)$ in the image domain whose value at each point (x,y) indicates quantitatively the intensity level of the moire in question, i.e. the particular intensity contribution of this moire to the image superposition. Note that although this moire is visible both in the image superposition $f(x,y)\cdot g(x,y)$ and in the extracted moire intensity profile $m_{k_1,k_2,k_3,k_4}(x,y)$, the latter does not contain the fine structure of the original images $f(x,y)$ and $g(x,y)$ but only the isolated form of the extracted (k_1,k_2,k_3,k_4)-moire. Moreover, in a single image superposition $f(x,y)\cdot g(x,y)$ several different moires may be visible simultaneously; but each of them will have a different moire intensity profile $m_{k_1,k_2,k_3,k_4}(x,y)$ of its own.

Let us now find the expressions for the location, the index and the amplitude of each of the impulses of the (k_1,k_2,k_3,k_4)-moire cluster. If $\mathbf{a}$ is the frequency vector of the (k_1,k_2,k_3,k_4)-impulse in the convolution and $\mathbf{b}$ is the orthogonal frequency vector of the $(-k_2,k_1,-k_4,k_3)$-impulse, then we have:

$$\begin{aligned} \mathbf{a} &= k_1\mathbf{f}_1 + k_2\mathbf{f}_2 + k_3\mathbf{f}_3 + k_4\mathbf{f}_4 \\ \mathbf{b} &= -k_2\mathbf{f}_1 + k_1\mathbf{f}_2 - k_4\mathbf{f}_3 + k_3\mathbf{f}_4 \end{aligned} \tag{13}$$

The index-vector of the (i,j)-th impulse in the (k_1,k_2,k_3,k_4)-moire cluster is, therefore:

$$i(k_1,k_2,k_3,k_4) + j(-k_2,k_1,-k_4,k_3) =$$

$$(ik_1 - jk_2,\ ik_2 + jk_1,\ ik_3 - jk_4,\ ik_4 + jk_3). \tag{14}$$

And furthermore, since the geometric locations of the (k_1,k_2,k_3,k_4)- and $(-k_2,k_1,-k_4,k_3)$-impulses are $\mathbf{a}$ and $\mathbf{b}$ (they are the basis vectors which span the lattice $L_M(u,v)$, the support

spectrum-convolution is the product of the (i,j)-impulse of the (k_1,k_2)-subnailbed of $F(u,v)$ and the (i,j)-impulse of the (k_3,k_4)-subnailbed of $G(u,v)$. This means that:

Result 3: (2D generalization of Result 1): The impulse amplitudes of the (k_1,k_2,k_3,k_4)-moire cluster in the spectrum-convolution are the term-by-term product of the (k_1,k_2)-subnailbed of $F(u,v)$ and the (k_3,k_4)-subnailbed of $G(u,v)$.

For example, in the case of the simplest first-order moire between the dot-screens $f(x,y)$ and $g(x,y)$, the (1,0,-1,0)-moire (see FIG. 2C), the amplitudes of the moire-cluster impulses in the spectrum-convolution are given by: $c_{i,j} = a^{(f)}_{i,j}\, a^{(g)}_{-i,-j}$. This means that in this case the moire-cluster is simply a term-by-term product of the nailbeds $F(u,v)$ and $G(-u,-v)$ of the original images $f(x,y)$ and $g(-x,-y)$. For the second-order (1,2,-2,-1)-moire (see FIG. 2B) the amplitudes of the moire-cluster impulses are: $c_{i,j} = a^{(f)}_{i-2j,2i+j}\, a^{(g)}_{-2i+j,-i-2j}$.

Now, since we also know the exact locations of the impulses of the moire-cluster (according to Eq. (14)), the spectrum of the isolated moire in question is fully determined, and given analytically by:

$$M_{k_1,k_2,k_3,k_4}(u,v) = \sum_{i=-\infty}^{\infty} \sum_{j=-\infty}^{\infty} c_{i,j}\, \delta_{i\mathbf{a}+j\mathbf{b}}(u,v) \tag{19}$$

where $\delta_{\mathbf{f}}(u,v)$ denotes an impulse located at the frequency-vector $\mathbf{f}$ in the spectrum. Therefore, we can reconstruct the intensity profile of the moire, back in the image domain, by formally taking the inverse Fourier transform of the isolated moire cluster. Practically, this can be done either by interpreting the moire cluster as a 2D Fourier series, and summing up the corresponding sinusoidal functions (up to the desired precision); or, more efficiently, by approximating the continuous inverse Fourier transform of the isolated moire-cluster by means of the inverse 2D discrete Fourier transform (using FFT).

As in the case of grating superposition, the spectral domain term-by-term multiplication of the moire-clusters can be interpreted directly in the image domain by means of the 2D version of the T-convolution theorem:

2D T-convolution theorem: Let $f(x,y)$ and $g(x,y)$ be doubly periodic functions of period T_x, T_y integrable on a one-period interval ($0 \le x \le T_x,\ 0 \le y \le T_y$), and let $\{F_{m,n}\}$

$F(u,v)$ and $G(-u,-v)$ themselves: $c_{i,j} = a^{(f)}_{i,j}\, a^{(g)}_{-i,-j}$. Since the impulse locations of this moire-cluster are also known, according to Eq. (3), we can obtain the intensity profile of the (1,0,-1,0)-moire by extracting this moire-cluster from the full spectrum-convolution, and taking its inverse Fourier transform.

However, according to Result 4, the intensity profile of the (1,0,-1,0)-moire can also be interpreted directly in the image domain: in this special case the moire intensity profile is simply a T-convolution of the original images $f(x,y)$ and $g(-x,-y)$ (after undergoing the necessary stretching and rotations to make their periods, or their supporting lattices in the spectrum, coincide).

Let us see now how T-convolution fully explains the moire intensity profile forms and the striking visual effects observed in superpositions of dot-screens with any chosen dot shapes, such as in FIG. 3 or FIG. 4. In these figures the moire is obtained by superposing two dot-screens having identical frequencies, with just a small angle difference α; this implies that in this case we are dealing, indeed, with a (1,0,-1,0)-moire. In the example of FIG. 4, dot-screen 41 consists of black "1"-shaped dots, and dot-screens 40 and 41 consist of black circular dot shapes. Each of the dot-screens 40, 41 and 42 consists of gradually increasing dots, with identical frequencies, and the superposition angle between the dot-screens is 4 degrees.

Case 1: As can be seen in FIG. 4, the form of the moire intensity profiles in the superposition is most clear-cut and striking where one of the two dot-screens is relatively dark (see 43 and 44 in FIG. 4). This happens because the dark screen includes only tiny white dots, which play in the T-convolution the role of very narrow pulses with amplitude 1. As shown in FIG. 5A, the T-convolution of such narrow pulses 50 (from one dot-screen) and dots 51 of any chosen shape (from a second dot-screen) gives dots 52 of the same chosen shape, in which the zero values remain at zero, the 1 values are scaled down to the value A (the volume or the area of the narrow white pulse divided by the total cell area, $T_x \cdot T_y$), and the sharp step transitions are replaced by slightly softer ramps. This means that the dot shape received in the normalized moire-period is practically identical to the dot shape of the second screen, except that its white areas turn darker. However, this normalized moire-period is stretched back into the real size of the moire-period T_M, as it is determined by Eqs. (5) and (6) (or in our case, according to Eq. (8), by the angle

of the original screens (or an intermediate orientation), the moire intensity profiles appear in a perpendicular direction. This fact is explained as follows:

As we have seen, the orientation of the moire is determined by the location of the fundamental impulses of the moire-cluster in the spectrum, i.e. by the location of the basis vectors **a** and **b** (Eq. (13)). In the case of the (1,0,-1,0)-moire these vectors are reduced to:

$$\begin{aligned} \mathbf{a} &= \mathbf{f}_1 - \mathbf{f}_3 \\ \mathbf{b} &= \mathbf{f}_2 - \mathbf{f}_4 \end{aligned} \qquad (21)$$

And in fact, as it can be seen in FIG. 2C, when the two original dot-screens have the same frequency, these basis vectors are rotated by about 90 degrees from the directions of the frequency vectors $\mathbf{f}_i$ of the two original dot-screens. This means that the (1,0,-1,0)-moire cluster (and the moire intensity profile it generates in the image domain) are rotated by about 90 degrees relative to the original dot-screens $f(x,y)$ and $g(x,y)$. Note that the precise period and angle of this moire can be found by formulas (8) which were derived for the (1,-1)-moire between two line-gratings with identical periods T and angle difference of α.

Obviously, the fact that the direction of the moire intensity profile is almost perpendicular to the direction of the original dot-screens is a property of the (1,0,-1,0)-moire between two dot-screens having identical frequencies; in other cases the angle of the moire may be different. In all cases the moire angle can be found by Eqs. (5) and (6).

Further details about more complex moires and moires of higher order are disclosed in detail in "Amidror94". In general, in order to obtain a (k_1,k_2,k_3,k_4)-moire in the superposition of two dot-screens, the frequencies f_i and the angles θ_i of the two dot-screens have to be chosen in accordance with Eqs. (5) and (6), so that the frequency of the (k_1,k_2,k_3,k_4)-impulse is located close to the origin of the frequency spectrum, within the range of visible frequencies.

underlying source image, and therefore they behave in a similar manner as screens comprising small white dots, having the same frequency. However, since the substrate between neighboring microlenses in the microlens array is transparent and not black, microlens arrays have the advange of letting the incident light pass through the array. They can therefore be used for producing moire intensity profiles either by reflection or by transmission, and the document including the basic screen may be printed on any support, opaque or transparent.

The comparison in step d) above can be done either by human biosystems (a human eye and brain), or by means of an apparatus described later in the present disclosure. In the latter case, comparing the moire intensity profile with a prestored moire intensity profile can be made by matching techniques, to which a reference is made in the section "Computer-based authentication of documents by matching prestored and acquired moire intensity profiles" below.

The prestored moire intensity profile (also called: "reference moire intensity profile") can be obtained either by image acquisition, for example by a CCD camera, of the superposition of a sample basic screen and a master screen, or it can be obtained by precalculation. The precalculation can be done, as explained earlier in the present disclosure, either in the image domain (by means of a normalized T-convolution of the basic screen and the master screen), or in the spectral domain (by extracting from the convolution of the frequency spectrum of the basic screen and the frequency spectrum of the master screen those impulses describing the (k_1,k_2,k_3,k_4)-moire, and by applying to said impulses an inverse Fourier transform). In the case where a microlens array is used as a master screen, the frequency spectrum of the microlens array is considered to be the frequency spectrum of the equivalent dot-screen, having the same frequency and orientation as the microlens array.

In the case where the basic screen is formed as a part of a halftoned image printed on the document, the basic screen will not be distinguishable by the naked eye from other areas on the document. However, when authenticating the document according to the present invention, the moire intensity profile will become immediatly apparent.

the basic and the master screens are required to have an orientation close to 180 degrees (or 0 degrees), according to the explanation given in the section "The orientation of the (1,0,-1,0)-moire intensity profiles" above.

FIG. 6 shows an example of a basic screen with a basic screen dot shape of the digit "1", which is generated with varying intensity levels using the dither matrix shown in FIG. 7A. FIG. 7B shows a magnified view of a small portion of this basic screen, and how it is built by the dither matrix of FIG. 7A. FIG. 8 shows an example of a master screen which is generated with the dither matrix shown in FIG. 9A (with darker intensity levels than the basic screen, in order to obtain small white dots). FIG. 9B shows a magnified view of a small portion of this master screen, and how it is built by the dither matrix of FIG. 9A. Note that FIG. 6 and FIG. 8 are reproduced here on a 300 dot-per-inch printer in order to show the screen details; on the real banknote the screens will normally be reproduced by a system whose resolution is at least 1270 or 2540 dots-per-inch. The moire intensity profile which is obtained when the basic screen and the master screen are superposed has the form of the digit "1", as shown by 43 in FIG. 4.

Example 2. Basic screen on document and master screen on separate support

As an alternative to Example 1, a banknote may contain a basic screen, which is produced by screen dots of a chosen size and shape (or possibly, by screen dots of varying size and shape, being incorporated in a halftoned image). The banknote is printed on a transparent support. The master screen may be identical to the master screen described in Example 1, but it is not printed on the banknote itself but rather on a separate transparent support, and the banknote can be authenticated by superposing the basic screen of the banknote with the separate master screen. For example, the superposition moire may be visualized by laying the banknote on the master screen, which may be fixed on a transparent sheet of plastic and attached on the top of a box containing a diffuse light source.

Another possible way of using colored dot-screens in the present invention is by using a basic screen whose individual screen elements are composed of sub-elements of different colors. (Note that the term "screen element" is used hereinafter to indicate a full 2D period of the dot-screen; it refers both to the screen dot which appears within this 2D period and to the background area which fills the rest of the period). An example of such a basic screen is illustrated in FIG. 14A, in which each of the screen dots of the basic screen has a triangular shape, and is sub-divided into sub-elements of different colors, as indicated by the different hachures in FIG. 14A, where each type of hachure represents a different color (for example: cyan, magenta, yellow and black). When a black-and-white master screen is superposed on such a multichromatic basic screen, a similar multichromatic moire effect is obtained, where not only the shape of the moire profiles is determined by the screen elements of the basic screen but also their colors. For example, in the case of the basic screen shown in FIG. 14A, the moire profiles obtained will be triangular, and each of them will be sub-divided into colored zones like in FIG. 14A. An important advantage of this method as an anticounterfeiting means is gained from the extreme difficulty in printing perfectly juxtaposed sub-elements of the screen dots, due to the high precision it requires between the different colors in multi-pass color printing. Only the best high-performance security printing equipment which is used for printing security documents such as banknotes is capable of giving the required precision in the alignment (hereinafter: "registration") of the different colors. Registration errors which are unavoidable when counterfeiting the document on lower-performance equipment will cause small shifts between the different colored sub-elements of the basic screen elements; such registration errors will be largely magnified by the moire effect, and they will significantly corrupt the form and the color of the moire profiles obtained by the master screen.

In practice, a multichromatic basic screen like the one shown in FIG. 14A can be generated by the same method as that described in "Example 1" above, with one dither matrix for each of the colors of the multichromatic basic screen. In the example of FIG. 14A, each screen element is generated by four dither matrices: one for the cyan pixels, one for the magenta pixels, one for the yellow pixels, and finally, one for the black pixels. Each of these single-color dither matrices is built in the same way as described in "Example 1", where only the dither matrix elements of the single color in question are numbered,

(b) The composite basic screen method. In this method the masked basic screen is a composite basic screen which is composed of two or more different dot-screens, each carrying its own information, that are superposed on each other.

(c) The perturbation patterns method. In this method a masked basic screen is obtained by altering the basic screen itself. This can be done by introduction of perturbation patterns into the basic screen by means of mathematical, statistical or logical Boolean operations. An example of this method is the introduction of any sort of statistical noise into the basic screen. The perturbation patterns can alter the original dither matrix used to generate the basic screen.

(d) Any combination of methods (a) (b) and (c).

As will become clear in the explanation below, if the new superposed masking layer (or respectively, the inserted perturbation) is non-periodic, or if it is periodic but it has a different period and/or orientation than the basic screen, this masking effect will not hamper the appearance of the moire intensity profiles when the master screen is superposed, but it will prevent the visualization of the information carried by the basic screen without using the master screen (for example, by a mere inspection of the document under a microscope).

Furthermore, since masked basic screens are generated by a computer program, they can be made so complex that even professionals in the graphic arts cannot re-engineer them without having the original computing programs specially developed for creating them.

Masking of information carried by a basic screen will now be exemplified by means of three techniques described below, which are provided in illustrative and non-limiting manner. Techniques 1 and 2 are provided as examples of a composite basic screen method, and technique 3 is given as an example of a perturbation patterns method.

Technique 1: The composite basic screen method with a single master screen

This technique, which illustrates the composite basic screen method, will be most clearly understood by means of the following case. Assume we are given two regular dot-screens

Thus, although the composite basic screen appearing on the document is scrambled and unintelligible, two different moire intensity profiles (in the example of FIG. 11C: the texts "EPFL/LSP" and "USA/$50") can become clearly visible when the appropriate master screen is superposed on the composite basic screen, each of the two moire intensity profiles being visible in a different orientation of the master screen.

Since the microstructure of the composite basic screen is unintelligible, and the individual screen dot shapes can only be made visible by superposing the appropriate master screen on top of the composite basic screen, it is therefore clear that if the master screen is not rendered public, the present technique becomes a covert anticounterfeit means, which can only be detected by the competent authorities or by automatic devices which possess the master screen.

This method is not limited to composite basic screens which are composed of two superposed dot-screens. On the contrary, further advantages can be obtained by using a composite basic screen which consists of more than two superposed dot-screens, possibly of different colors. For example, a composite basic screen may consist of three dot-screens with different dot shapes which are superposed with angle differences of 30 degrees (in which case no superposition moire is generated, as already known in the art of color printing). In this case, three different moire intensity profiles will be obtained by the master screen at angle differences of 30 degrees. However, some benefits can also be gained by using a composite basic screen in which some of the superposed dot-screens do generate a weak, visible moire effect; this weak visible moire effect may have a nice geometric form and serve as a decorative pattern on the document, while more dominant and completely different moire intensity profiles (for example: "EPFL/LSP" or "USA/$50") are revealed on top of this decorative pattern by using the master screen. (A weak moire effect can be generated, for example, by using for the basic screens in question lower gray levels, i.e. smaller screen dots.)

It should be noted that a composite basic screen printed on the document in accordance with the present invention need not necessarily be of a constant intensity level. On the contrary, it may include dots of gradually varying sizes and shapes, and it can be incorporated (or dissimulated) within any halftoned image printed on the document (such

moire intensity profiles can serve as a public authentication means of the document, while the other moire intensity profiles hidden in the same composite basic screen are not accessible to the general public.

It should be noted that as is the case in technique 1, the composite basic screen printed on the document may include dots of gradually varying sizes and shapes, and it can be incorporated (or dissimulated) within any halftoned image printed on the document, as already explained in the case of technique 1.

Note that any of the master screens in the multiple master screen variant can also be implemented by a microlens array with the appropriate angles and frequencies.

Technique 3: The irregular sub-element alterations technique

This technique is an example of the perturbation patterns method, in which a basic screen (or a composite basic screen) on the document is rendered unintelligible by means of the introduction of perturbation patterns. Perturbation patterns can be introduced into the basic screen to render it unintelligible in several different ways. For the sake of example, in the present technique this is done by means of irregular sub-element alterations. This can be most clearly illustrated by means of the following example.

Assume we are given a dot-screen whose screen dot has the shape of "EPFL/LSP" as in FIG. 11A. Each part of the screen dot (in the present example, each individual letter) can be further divided into a certain number of sub-elements. For example, FIG. 12A shows a possible way to divide the letter "E" into sub-elements. This division into sub-elements should be done in such a way that missing sub-elements (such as 120 in FIG. 12B) render the letter unrecognizable, as shown for example in FIGS. 12B–12D. Moreover, additional segments or shifting of sub-elements (such as 121 in FIG. 12F) can also be used to render the letter unintelligible, as shown for example in FIGS. 12E and 12F.

Since the moire intensity profiles in the screen superposition are obtained by T-convolution, a small rate of perturbations (in the present example: sub-element alterations) in a screen element will hardly influence the resulting moire intensity profile, due to the

choosing from the variants generated in step 2 those in which the original form is the least recognizable.

4. Then, the designer or a computer program generates the large super-tile (which consists of $m \times n$ screen elements) by choosing for each occurrence of any screen element part within each of the $m \times n$ screen elements a different variant (from the set of N variants selected for this screen element part in step 3). This is done in a statistically uniform way, where each sub-element is missing in only up to 10% – 20% of the occurrences of the screen element part in the super-tile, and each additional sub-element appears in no more than 10% – 20% of the occurrences of the screen element part in the super-tile.

5. This super-tile is then used, as already known in the art, for generating the masked basic screen for the case of the irregular sub-element alterations technique.

The irregular sub-element alterations technique can also be used for performing intensity level variations and halftoning with the masked basic screen. This can be done using the dither matrix method, as illustrated in FIGS. 6, 7A and 7B for the simple case of a "1"-shaped screen dot, but this time using an altered super-dither matrix whose size equals that of the super-tile. This altered super-dither matrix can be obtained, for example, by first preparing an elementary dither matrix which corresponds to the original, unaltered screen element. Then, variants of this elementary dither matrix are obtained by performing the sub-element alterations (the omitting, shifting, exchanging or adding of sub-elements) inside copies of the original elementary dither matrix, and these variants are then incorporated into the altered super-dither matrix, in accordance with steps 1–5 above. After incorporating the sub-element alterations within the super-dither matrix, dither threshold levels in the super-dither matrix can be renumbered so as to generate a continuous sequence of threshold levels.

In the case of a multicolor basic screen, a similar effect can also be obtained by irregular alterations in the color of the sub-elements. Furthermore, as shown in FIGS. 16A and 16B, in the multichromatic case the screen dots of the basic screen can be divided into sub-elements of different colors, while the background (the area between the screen dots) can be divided into sub-elements of other colors (for example, brighter colors). By way of

$$T_1 = 1/\sqrt{a_u^2 + a_v^2}$$

$$T_2 = 1/\sqrt{b_u^2 + b_v^2}$$

As explained earlier in the present disclosure, the prestored moire intensity profile can be obtained either by acquisition or by precalculation. However, in order to take into account the influence of the image acquisition device, for example a CCD camera, it is advantageous to obtain the prestored moire intensity profile by the acquisition of the moire intensity profile produced by the superposition of the master screen and an original document incorporating the basic screen. Since the acquisition of the prestored moire intensity profile only occurs once, a careful adjustment of the superposition ensures that the orientations of the main axes of the acquired prestored moire intensity profile correspond exactly to the precalculated orientations φ_1, φ_2. Hence, the periods P_1, P_2 of the acquired presored moire intensity profile (in terms of the acquisition device units, for example, pixels), correspond to the precalculated periods T_1, T_2 (in terms of document space units). The periods P_1, P_2 in terms of the acquisition device units can be found by intersecting the prestored moire intensity profile with a straight line parallel to one of the two main axes, say the first axis, of the prestored moire intensity profile. A discrete straight line segment representing the intensity profile along this straight line is obtained by resampling the straight line at the acquired moire intensity profile resolution. The period P_1 of the resulting discrete straight line segment is measured, and period P_2 of the prestored moire intensity profile along the other main axis may be obtained for example by calculating $P_2 = P_1 (T_2/T_1)$.

Consider, as an exemple, FIG. 15A, showing a prestored moire intensity profile which is schematically represented in the drawing by triangular elements 150. In this example, the main axes of the prestored moire intensity profile are axis 151 at orientation φ_1 and axis 152 at orientation φ_2. Along the first main axis 151 the period of the prestored moire intensity is P_1, and along the second main axis 152 the period of the prestored moire intensity is P_2.

Note that hereinafter the prestored moire intensity profile will also be called "prestored moire image", since the prestored moire intensity profile is stored in the same way as a

The following paragraph describes the method of this example in more details. It describes how rotation angle error δ and scaling error σ are recovered, and also mentions conditions for rejecting or accepting a document. In the following explanation it is assumed that the scaling error σ is larger than a certain fraction σ_{min} (say, 0.5) and smaller than a certain number σ_{max} (say, 2). The term "quasi-period" will mean in the following explanation a distance between two consecutive low-to-high (or high-to-low) intensity transitions of a possibly non-periodic one-dimensional signal.

The rotation angle error δ and the scaling error σ between the prestored moire intensity profile and an acquired moire intensity profile can be determined, for example, by intersecting the acquired moire intensity profile with a straight line parallel to one of the two main axes, say the first axis, of the prestored moire intensity profile. A discrete straight line segment representing the intensity profile along this straight line is obtained by resampling the straight line at the acquired moire intensity profile resolution. The resulting discrete straight line segment (for example segment 155 in FIG. 15B, shown in the drawing as a continuous line) is subsequently analyzed and checked for a valid intensity variation along the line; a valid intensity variation is defined as an intensity variation with a quasi-period not smaller than σ_{min} (for example, 0.5) times the smallest of the two periods P_1, P_2 of the prestored moire intensity profile and not larger than σ_{max} (for example, 2) times the largest of the two periods P_1, P_2 of the prestored moire intensity profile. If such a valid intensity variation is not found, or if it is below a given intensity threshold, for example below half the maximal intensity difference, another discrete straight line segment is generated parallel to the previous discrete straight line segment (this new discrete straight line segment is called "a parallel instance" of the previous discrete straight line segment). This parallel discrete straight line segment is generated at a distance γ (156 in FIG. 15B) apart from the previous discrete straight line segment (the distance γ being, for example, 1/4 of period P_2). Line segment 157 in FIG. 15B is an example of such a parallel discrete straight line segment. If again no valid intensity variation is detected, further parallel discrete straight line segments are generated as before at a distance γ apart from each other and checked for valid intensity variations. If no valid intensity variation is detected after having generated discrete straight line segments across, for example, twice the full period P_2, the document is rejected. In the case where a valid intensity variation is detected, it is checked if successive quasi-periods of the intensity

$1/\sigma$, so as to obtain exactly the same periods and orientations as the periods (P_1,P_2) and orientations (φ_1, φ_2) of the prestored moire intensity profile. (Regarding image extraction, affine transformation, scaling and rotation, see for example the book "Digital Image Processing", by W. K. Pratt, Chapter 14: "Geometrical image modification").

The geometrically corrected moire intensity profile thus obtained is then matched with the prestored moire intensity profile so as to produce a degree of proximity between the two. Matching a given image with a prestored image can be done, for example, by template matching, as described in the book "Digital Image Processing and Computer Vision", by R. J. Schalkoff, pp 279-286. For template matching, one may use the correlation techniques which give an intensity proximity value $C(s_x,s_y)$ between the two images as a function of their relative shift (s_x,s_y). The largest intensity proximity value gives the translation error $(\tau_x,\tau_y) = (s_x,s_y)$. If the so-computed largest intensity proximity value is higher than an experimentally determined intensity proximity threshold value the document is accepted, and otherwise the document is rejected.

Accordingly, the method described in detail in the example above, where comparing a moire intensity profile with a prestored moire intensity profile is done by computer-based matching, which requires an acquisition of a moire intensity profile and a geometrical correction of a rotation angle error and of a scaling error in the acquired moire intensity profile, comprises the steps of:

a) acquiring a moire intensity profile by an image acquisition means;

b) intersecting the acquired moire intensity profile with a straigtht line parallel to a main axis of the prestored moire intensity profile;

c) computing a discrete straight line segment representing the acquired moire intensity profile along the straight line by resampling the straight line intersecting the acquired moire intensity profile at the resolution of the acquired moire intensity profile;

d) checking the considered discrete straight line segment as well as parallel instances of it for valid intensity variations defined as intensity variations with a quasi-period not smaller than σ_{min} times the smallest of the two periods P_1, P_2 of the prestored moire

book "Computer Graphics: Principles and Practice", by J.D. Foley, A. Van Dam, S.K. Feiner and J.F. Hughes, Section 13.3.3, p. 589).

Matching a prestored color moire image with an acquired color moire image (after it has been geometrically corrected) can be done in a similar manner as in the black-and-white case, using the Y coordinate as the achromatic moire intensity profile. As in the black-and-white case, the largest intensity proximity value and the translation error (τ_x, τ_y) (i.e. the phase differences in the two main directions between the prestored and the acquired moire images) can be found, for example, by template matching. Here, too, if the largest intensity proximity value is lower than an experimentally determined intensity proximity threshold value, the document is rejected. But if the intensity proximity value is higher than the experimentally determined proximity threshold value, the document undergoes an additional test using the chromaticity acceptance criterion, which is based on a chromatic Euclidian distance.

Using the same phase differences (τ_x, τ_y), a chromatic Euclidian distance in the IQ colorimetric plane is computed for each pixel between the geometrically corrected acquired moire image and the prestored moire image. The average chromatic Euclidian distance is a measure of a chromatic proximity between the acquired moire image and the prestored moire image: a small average chromatic Euclidian distance indicates a high degree of proximity, and vice versa. Using this criterion, a document is accepted if the average chromatic Euclidian distance is lower than an experimentally determined chromatic Euclidian distance threshold, and rejected if the average chromatic Euclidian distance is higher than an experimentally determined chromatic Euclidian distance threshold.

The maximal possible rotation angle error $\delta_{\max}$ can be experimentally determined by acquiring the moire image obtained when a document is fed by the document handling device with the greatest possible rotational feeding error, and by comparing the orientation of the so-acquired moire image with the orientation of the prestored moire image. Furthermore, various instances of the original document as well as reproductions of it (simulating counterfeited documents) may be acquired according to the method described above. The different intensity proximity values obtained for the original documents on the one hand, and for the reproductions on the other hand, enable the setting of the

the moire intensity profile is observed by reflection). If the authentication is made by visualization, i.e. by a human operator, human biosystems (a human eye and brain) are used as a means for the acquisition of the moire intensity profile produced by the superposition of the basic screen and the master screen, and as a means for comparing the acquired moire intensity profile with a prestored moire intensity profile.

An apparatus for the automatic authentication of documents, whose block diagram is shown in FIG. 10, comprises a master screen 101 (either a dot-screen or a microlens array), an image acquisition means (102) such as a CCD camera, a source of light (not shown in the drawing), and a comparing processor (103) for comparing the acquired moire intensity profile with a prestored moire intensity profile. In case the match fails, the document will not be authenticated and the document handling device of the apparatus (104) will reject the document. The comparing processor 103 can be realized by a microcomputer comprising a processor, memory and input-output ports. An integrated one-chip microcomputer can be used for that purpose. For automatic authentication, the image acquisition means 102 needs to be connected to the microprocessor (the comparing processor 103), which in turn controls a document handling device 104 for accepting or rejecting a document to be authenticated, according to the comparison operated by the microprocessor.

The prestored moire intensity profile can be obtained either by image acquisition, for example by means of a CCD camera, of the superposition of a sample basic screen and the master screen, or it can be obtained by precalculation. The precalculation can be done either in the image domain or in the spectral domain, as explained earlier in the present disclosure.

The comparing processor makes the image comparison by matching a given image with a prestored image; examples of ways of carrying out this comparison have been presented in detail in the previous section. This comparison produces at least one proximity value giving the degree of proximity between the acquired moire intensity profile and the prestored moire intensity profile. These proximity values are then used as criteria for making the document handling device accept or reject the document.

Yet a further advantage of the present invention is that it can be used, depending on the needs, either as an overt means of document protection which is intended for the general public; or as a covert means of protection which is only detectable by the competent authorities or by automatic authentication devices; or even as a combination of the two, thereby permitting various levels of protection. The covert methods disclosed in the present invention also have the additional advantage of being extremely difficult to re-engineer, thus further enhancing document security.

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CLAIMS

We claim:

1. A method for authenticating documents by using at least one moire intensity profile, the method comprising the steps of:

a) creating on a document a basic screen with at least one basic screen dot shape;

b) creating a master screen with a master screen dot shape;

c) superposing the master screen and the basic screen, thereby producing a moire intensity profile; and

d) comparing said moire intensity profile with a prestored moire intensity profile and depending on the result of the comparison, accepting or rejecting the document;

where the produced moire intensity profile is a normalized T-convolution of the basic screen and of the master screen and where the orientation and period of the produced moire intensity profile are determined by the orientations and periods of the basic screen and of the master screen.

2. The method of claim 1, where the master screen contains tiny dots and where the moire intensity profile is a magnified and rotated version of the basic screen dot shape.

3. The method of claim 1, where the prestored moire intensity profile is obtained by an operation selected from the set of operations comprising:

a) image acquisition of the superposition of the basic screen and the master screen;

b) precalculation in the image domain, by finding the normalized T-convolution of the basic screen and the master screen; and

determines which of the dot-screens generates the visible moire intensity profile with the superposed master screen.

11. The method of claim 10, where the composite basic screen comprises at least two dot-screens of different colors and where the moire intensity profile obtained by the superposition of the master screen and the composite basic screen approximates both the color and the intensity profile of each of said dot-screens.

12. The method of claim 10, where each of the superposed dot-screens of the composite basic screen has a different frequency, thereby requiring a different master screen for generating a moire intensity profile with each of said dot-screens.

13. The method of claim 9, where the masked basic screen is obtained by introduction of perturbation patterns into the basic screen.

14. The method of claim 13, where said perturbation patterns are obtained by means of operations selected from the group comprising: mathematical operations, statistical operations and logical Boolean operations.

15. The method of claim 13, where perturbation patterns are obtained by irregular alterations of sub-elements of the screen elements, the generation of the irregular alterations comprising the steps of:

a) dividing each screen element part into sub-elements;

b) generating for each of the screen element parts a series of variants by applying to each of the screen element parts operations selected from the set of operations comprising: omitting sub-elements, shifting sub-elements, exchanging sub-elements, and adding sub-elements;

c) selecting for each of the screen element parts a set of variants from the series of variants generated for it in step b);

c) computing a discrete straight line segment representing the acquired moire intensity profile along the straight line by resampling the straight line intersecting the acquired moire intensity profile at the resolution of the acquired moire intensity profile;

d) checking the considered discrete straight line segment as well as parallel instances of it for valid intensity variations defined as intensity variations with a quasi-period not smaller than $\sigma_{\min}$ times the smallest of the two periods P_1, P_2 of the prestored moire intensity profile and not larger than $\sigma_{\max}$ times the largest of the two periods P_1, P_2 of the prestored moire intensity profile;

e) rejecting the document in the case where no valid intensity variations occur in any of the parallel discrete straight line segment instances;

f) in the case of valid intensity variations, rotating the discrete straight line segment showing valid intensity variations until an angle δ is reached in which the rotated discrete straight line segment comprises successive identical quasi-periods P of intensity variations;

g) computing the scaling error $\sigma = P/P_1$;

h) using angle δ and scaling error σ to rotate by angle $-\delta$ and to scale by factor $1/\sigma$ a window of the acquired moire intensity profile containing at least one period of said acquired moire intensity profile, thereby obtaining a geometrically corrected moire intensity profile;

i) matching the so-obtained geometrically corrected moire intensity profile with the prestored moire intensity profile and obtaining a proximity value giving the proximity between the acquired moire intensity profile and the prestored moire intensity profile; and

j) rejecting the document if the proximity value is lower than an experimentally determined threshold.

20. The method of claim 19, where the basic screen is a color screen, and where the acquired moire intensity profile and the prestored moire intensity profile are, respectively,

24. The apparatus of claim 21, where the comparing means is a comparing processor controlling a document handling device accepting, respectively rejecting a document to be authenticated, according to the comparison operated by the comparing processor.

25. The apparatus of claim 24, where the comparing processor is a microcomputer comprising a processor, memory and input-output ports and where the image acquisition means is a CCD camera connected to said microcomputer.

26. A method for authenticating documents by using at least one moire intensity profile, the method comprising the steps of:

i) creating on a document a basic screen with at least one basic screen dot shape;

ii) creating a master screen with a master screen dot shape;

iii) superposing the master screen and the basic screen, thereby producing a moire intensity profile; and

iv) comparing said moire intensity profile with a prestored moire intensity profile and depending on the result of the comparison, accepting or rejecting the document;

where comparing a moire intensity profile with a prestored moire intensity profile is done by computer-based matching, which requires an acquisition of a moire intensity profile and a geometrical correction of a rotation angle error and of a scaling error in the acquired moire intensity profile, comprising the steps of:

a) acquiring a moire intensity profile by an image acquisition means;

b) intersecting the acquired moire intensity profile with a straigtht line parallel to a main axis of the prestored moire intensity profile;

c) computing a discrete straight line segment representing the acquired moire intensity profile along the straight line by resampling the straight line intersecting the acquired moire intensity profile at the resolution of the acquired moire intensity profile;

Euclidian distance in the chromatic IQ plane is computed between the geometrically corrected acquired color moire image and the prestored color moire image, and where the document is rejected if this chromatic Euclidian distance is higher than an experimentally determined chromatic Euclidian distance threshold.

c) precalculation in the spectral domain, by extracting from the convolution of the frequency spectrum of the basic screen and the frequency spectrum of the master screen those impulses describing a (k_1,k_2,k_3,k_4)-moire, and applying to said impulses an inverse Fourier transform.

4. The method of claim 1, where the basic screen and the master screen are located on a transparent support, and where comparing the moire intensity profile with a prestored moire intensity profile is done by visualization.

5. The method of claim 4, where the basic screen and the master screen are located on two different areas of the same document, thereby enabling the visualization of the moire intensity profile to be performed by superposition of the basic screen and the master screen of said document.

6. The method of claim 1, where the master screen is a microlens array.

7. The method of claim 6, where the document comprising the basic screen is printed on an opaque support, thereby allowing the moire intensity profile to be produced by reflection.

8. The method of claim 1, where the basic screen is a multichromatic basic screen whose individual elements are colored, thereby generating a color moire image when the master screen is superposed on said basic screen.

9. The method of claim 1, where at least one screen selected from the set comprising the basic screen and the master screen includes dots of gradually varying sizes and shapes.

10. The method of claim 1, where at least one screen selected from the set comprising the basic screen and the master screen is incorporated within a variable intensity halftoned image.

11. The method of claim 1, where at least one screen selected from the set comprising the basic screen and the master screen is a colored screen and includes dots of gradually varying sizes and shapes.

19. The method of claim 17, where perturbation patterns are obtained by irregular alterations of sub-elements of the screen elements, the generation of the irregular alterations comprising the steps of:

a) dividing each screen element part into sub-elements;

b) generating for each of the screen element parts a series of variants by applying to each of the screen element parts operations selected from the set of operations comprising: omitting sub-elements, shifting sub-elements, exchanging sub-elements, and adding sub-elements;

c) selecting for each of the screen element parts a set of variants from the series of variants generated for it in step b);

d) generating a super-tile comprising an integer number of screen elements by choosing for each occurrence of any screen element part within each of the screen elements of the super-tile a different variant, ensuring that missing sub-elements are missing only in up to 10% to 20% of the occurrences of the screen element part in the super-tile and that additional sub-elements appear in no more than 10% to 20% of the occurrences of the screen element part in the super-tile; and

e) using the super-tile for generating the masked basic screen.

20. The method of claim 19, where the basic screen is a multichromatic basic screen and where the set of operations applied to each of the screen element parts also comprises alterations of the color of the sub-elements, thereby turning the basic screen into a multichromatic mosaic of sub-elements which is difficult to counterfeit due to the required high registration accuracy.

21. The method of claim 13, where the masked basic screen is obtained by introduction of perturbation patterns into the dither matrix used for generating the basic screen.

h) using angle δ and scaling error σ to rotate by angle $-\delta$ and to scale by factor $1/\sigma$ a window of the acquired moire intensity profile containing at least one period of said acquired moire intensity profile, thereby obtaining a geometrically corrected moire intensity profile;

i) matching the so-obtained geometrically corrected moire intensity profile with the prestored moire intensity profile and obtaining a proximity value giving the proximity between the acquired moire intensity profile and the prestored moire intensity profile; and

j) rejecting the document if the proximity value is lower than an experimentally determined threshold.

24. The method of claim 23, where the basic screen is a color screen, and where the acquired moire intensity profile and the prestored moire intensity profile are, respectively, an acquired color moire image and a prestored color moire image, whose Y coordinate in the YIQ space is used as the achromatic moire intensity profile, and where in addition to the matching of the Y coordinates of the geometrically corrected acquired color moire image with the Y coordinates of the prestored color moire image, an average chromatic Euclidian distance in the chromatic IQ plane is computed between the geometrically corrected acquired color moire image and the prestored color moire image, and where the document is rejected if this chromatic Euclidian distance is higher than an experimentally determined chromatic Euclidian distance threshold.

25. An apparatus for authentication of documents making use of at least one moire intensity profile, the apparatus comprising:

a) a master screen;

b) an image acquisition means operable for acquiring a moire intensity profile produced by the superposition of a basic screen printed on a document and the master screen;

c) a source of light; and

where comparing a moire intensity profile with a prestored moire intensity profile is done by computer-based matching, which requires an acquisition of a moire intensity profile and a geometrical correction of a rotation angle error and of a scaling error in the acquired moire intensity profile, comprising the steps of:

a) acquiring a moire intensity profile by an image acquisition means;

b) intersecting the acquired moire intensity profile with a straigtht line parallel to a main axis of the prestored moire intensity profile;

c) computing a discrete straight line segment representing the acquired moire intensity profile along the straight line by resampling the straight line intersecting the acquired moire intensity profile at the resolution of the acquired moire intensity profile;

d) checking the considered discrete straight line segment as well as parallel instances of it for valid intensity variations defined as intensity variations with a quasi-period not smaller than $\sigma_{\min}$ times the smallest of the two periods P_1, P_2 of the prestored moire intensity profile and not larger than $\sigma_{\max}$ times the largest of the two periods P_1, P_2 of the prestored moire intensity profile;

e) rejecting the document in the case where no valid intensity variations occur in any of the parallel discrete straight line segment instances;

f) in the case of valid intensity variations, rotating the discrete straight line segment showing valid intensity variations until an angle δ is reached in which the rotated discrete straight line segment comprises successive identical quasi-periods P of intensity variations;

g) computing the scaling error $\sigma = P/P_1$;

h) using the angle δ and the scaling error σ to rotate by angle $-\delta$ and to scale by factor $1/\sigma$ a window of the acquired moire intensity profile containing at least one period of said acquired moire intensity profile, thereby obtaining a geometrically corrected moire intensity profile;

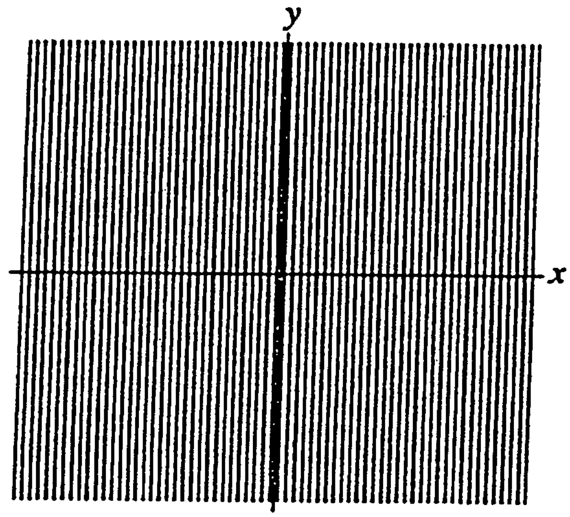


FIG. 1A

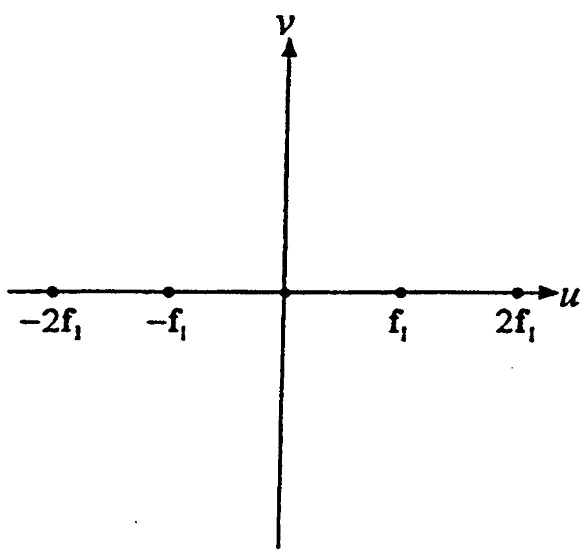


FIG. 1D

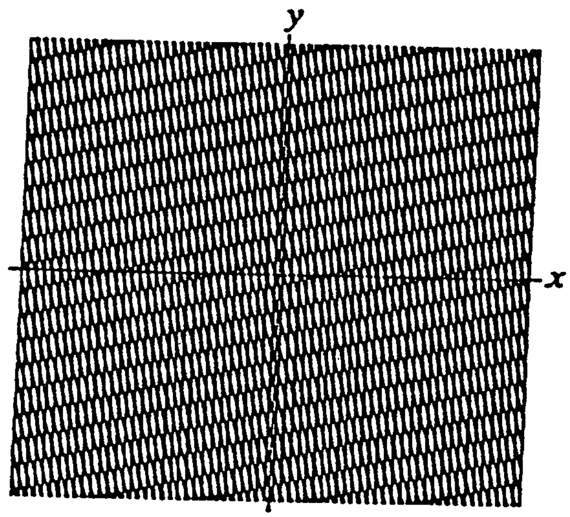


FIG. 1C

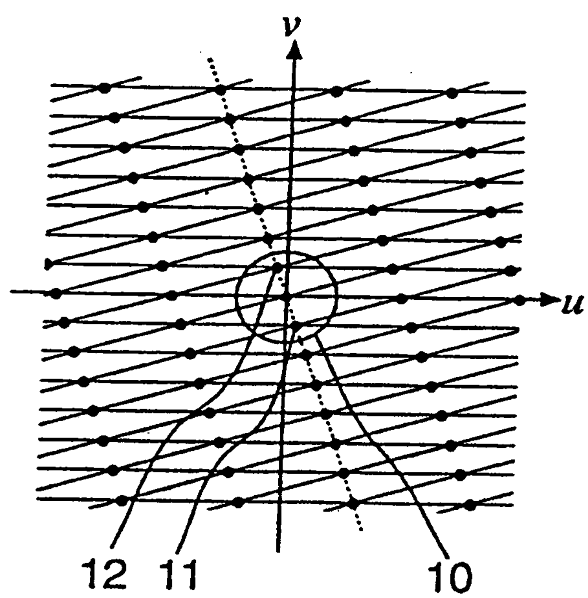


FIG. 1F

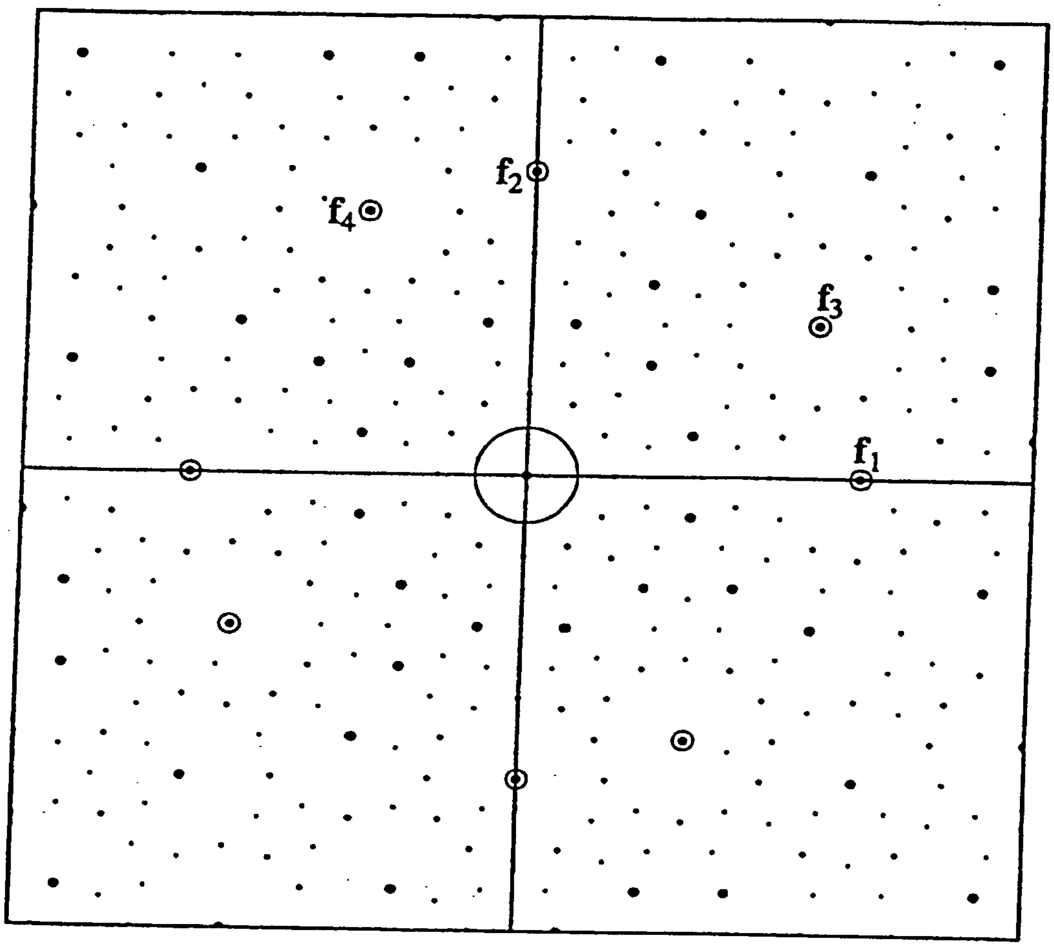


FIG. 2A

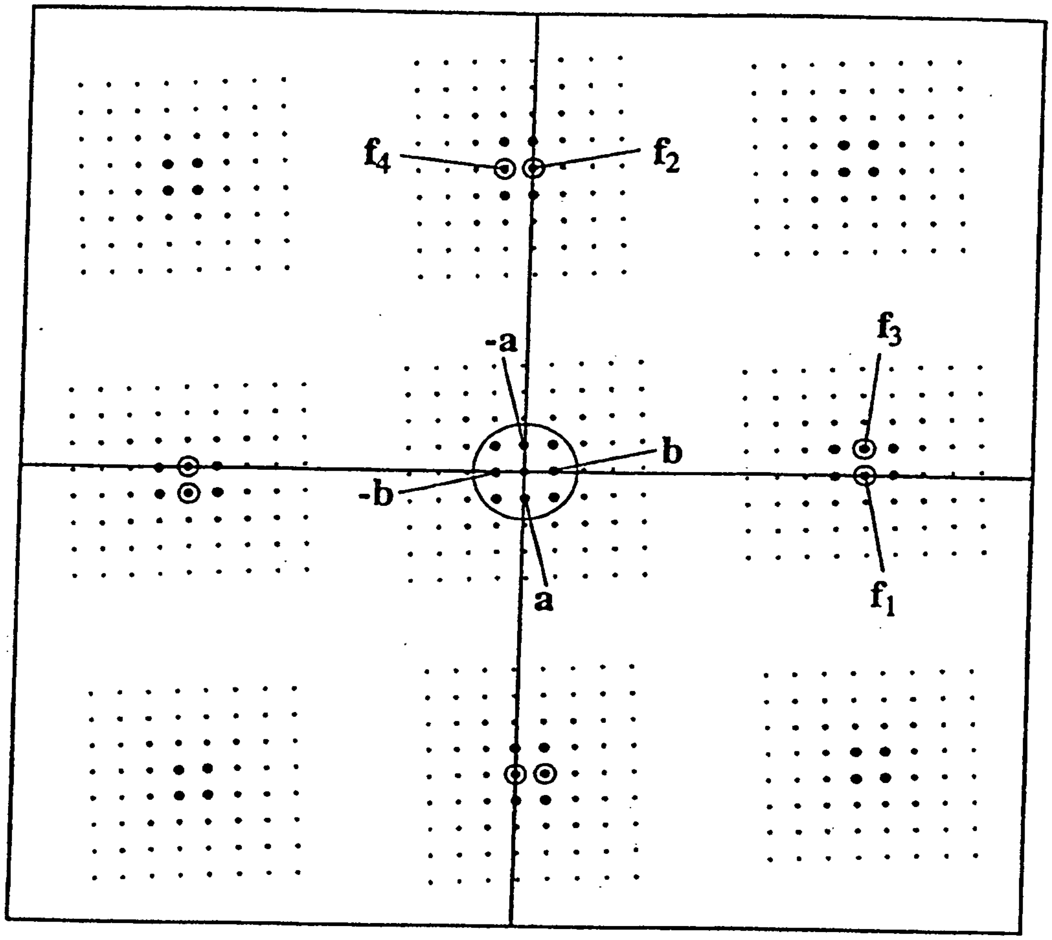


FIG. 2C

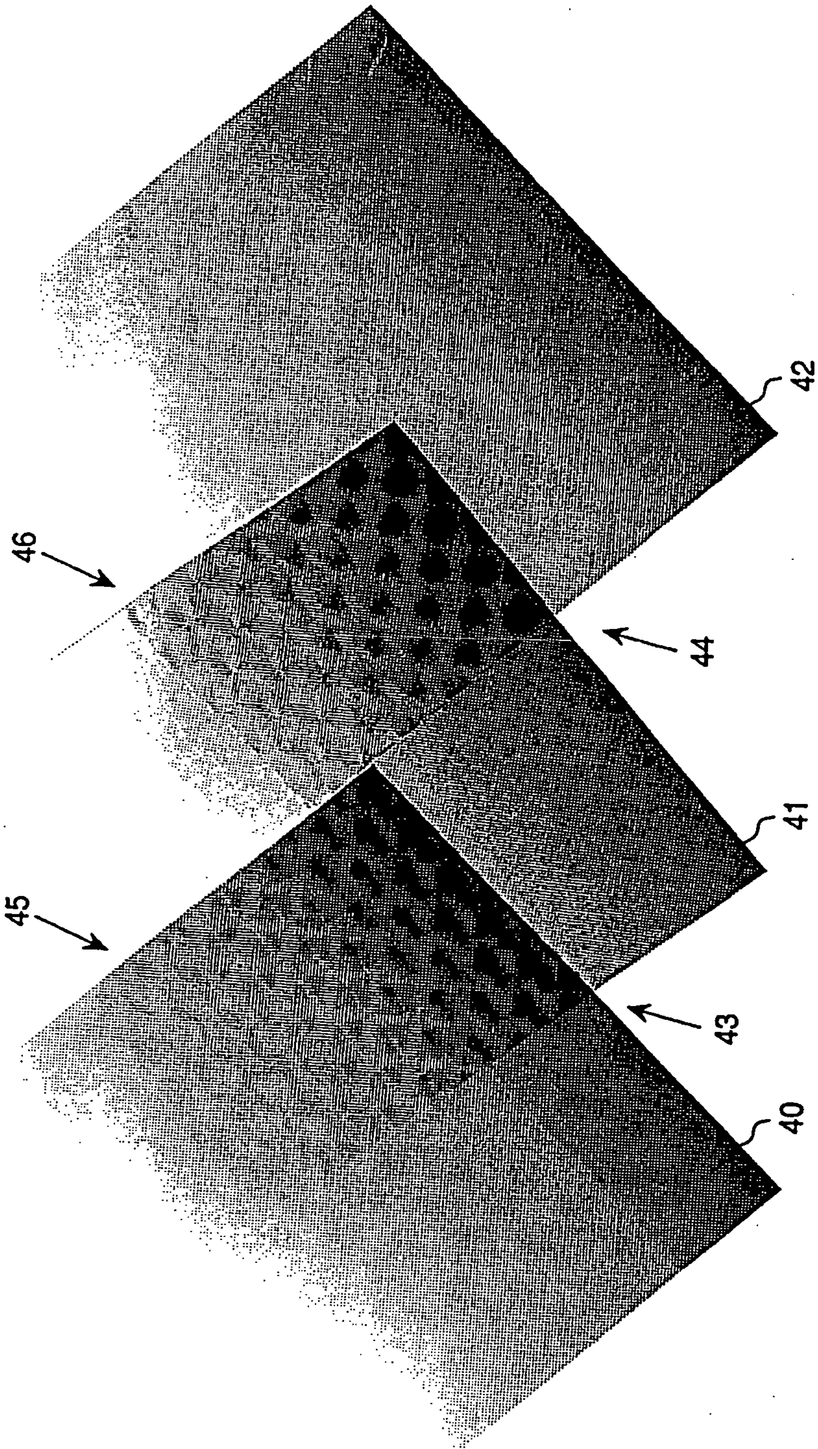


FIG. 4

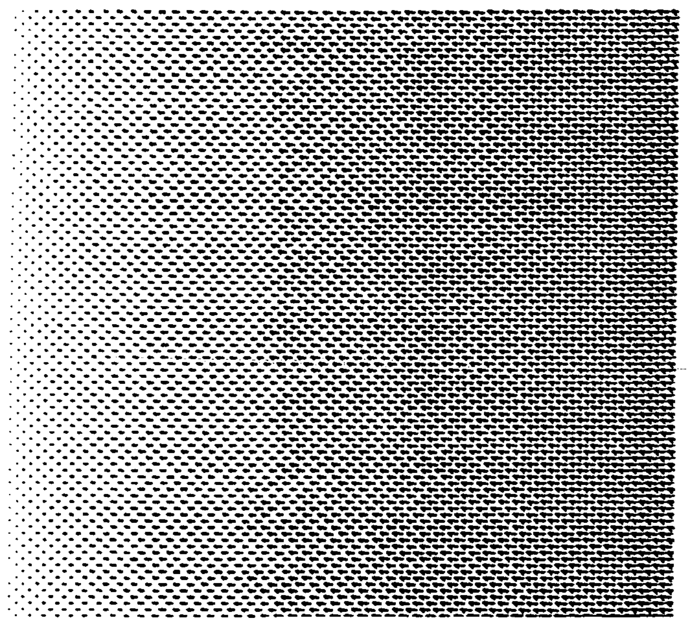


FIG. 6

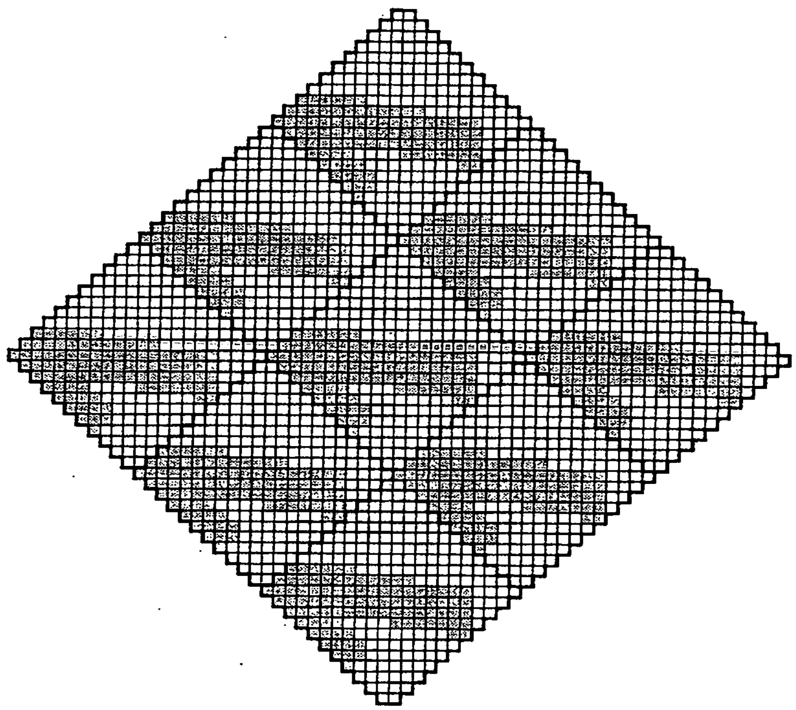


FIG. 7B

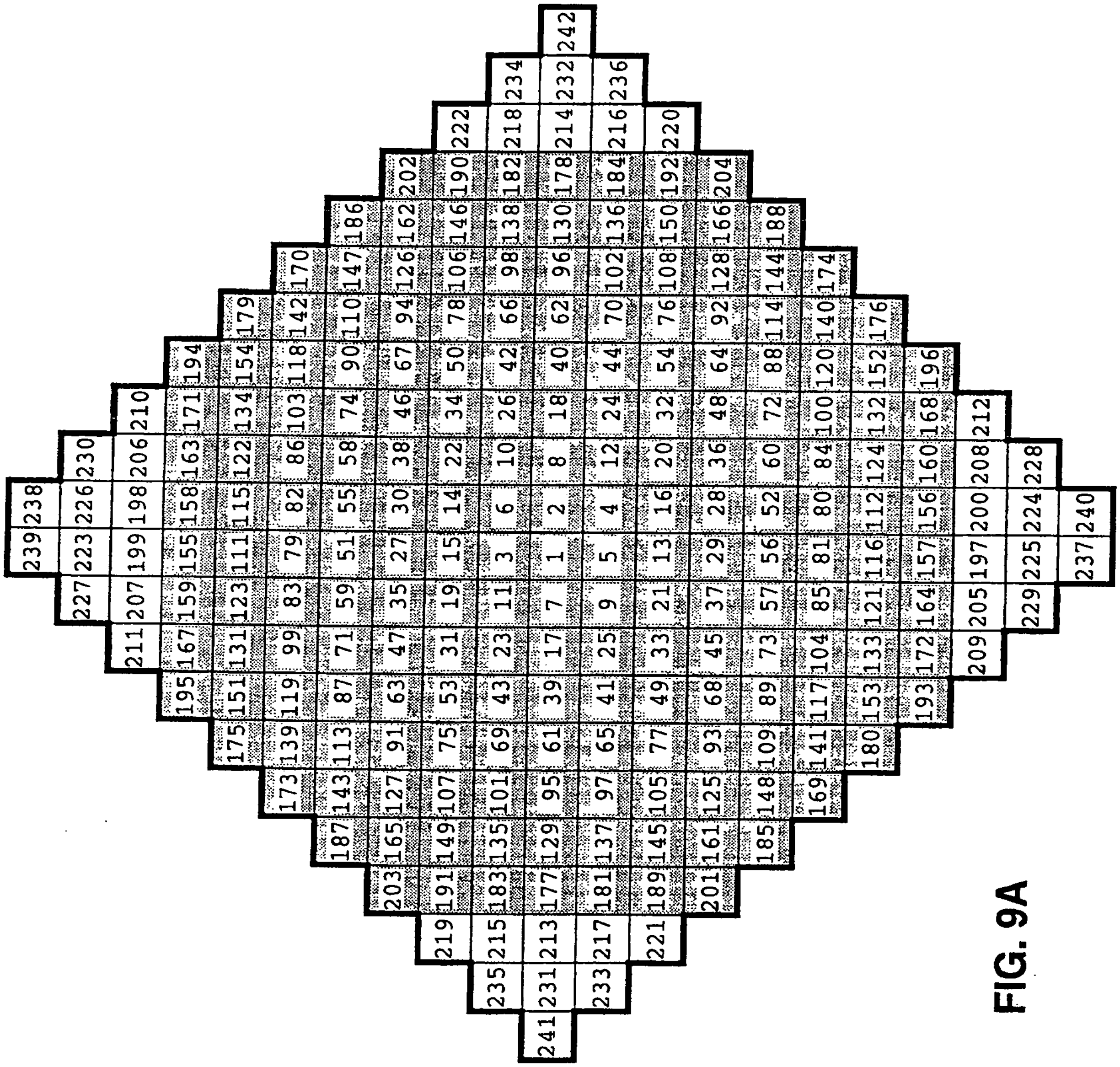


FIG. 9A

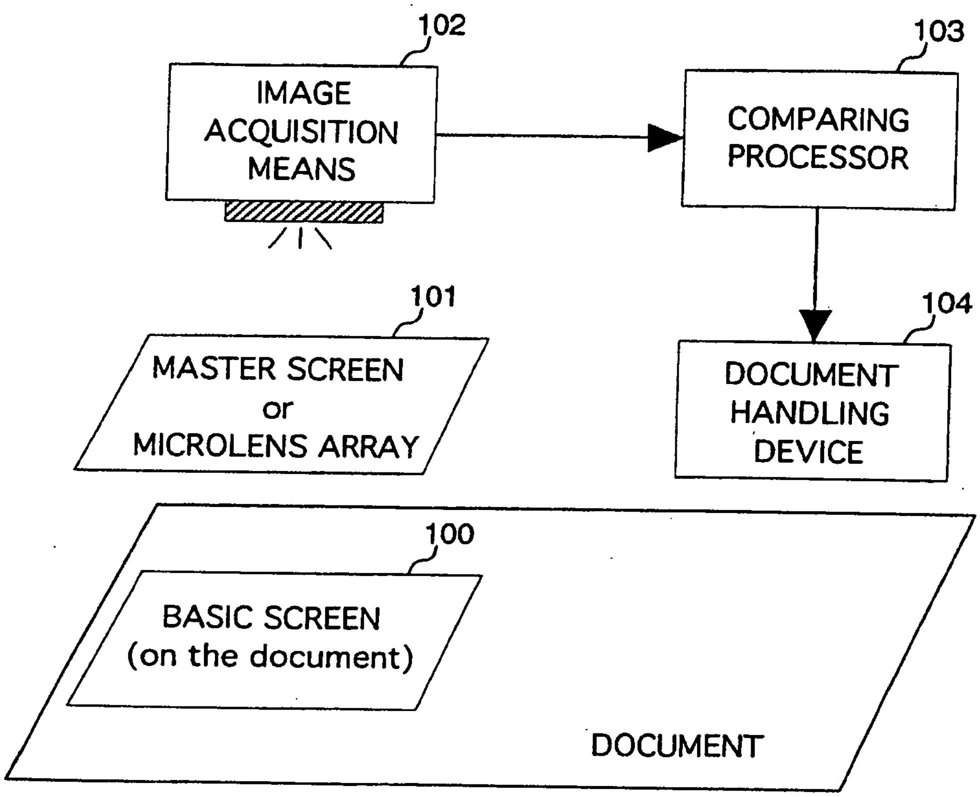

102
IMAGE ACQUISITION MEANS
103
COMPARING PROCESSOR
101
MASTER SCREEN or MICROLENS ARRAY
104
DOCUMENT HANDLING DEVICE
100
BASIC SCREEN (on the document)
DOCUMENT

FIG. 10

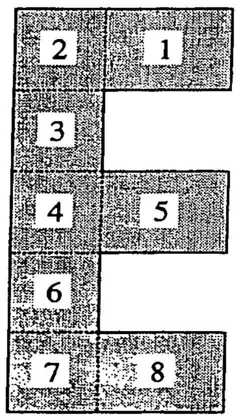


FIG. 12A

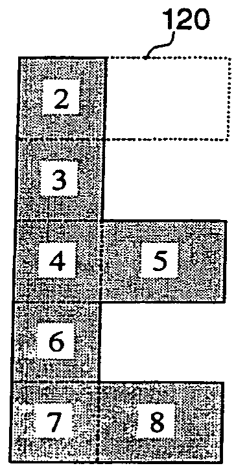


FIG. 12B

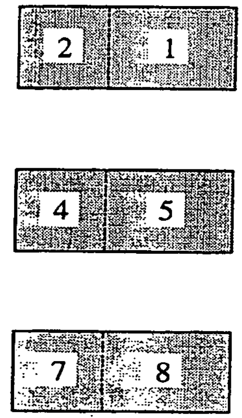


FIG. 12C

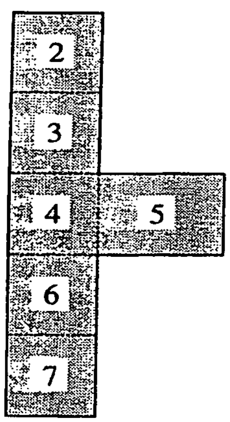


FIG. 12D

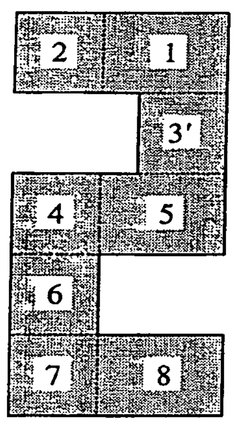


FIG. 12E

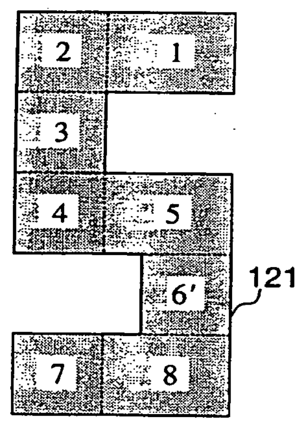


FIG. 12F

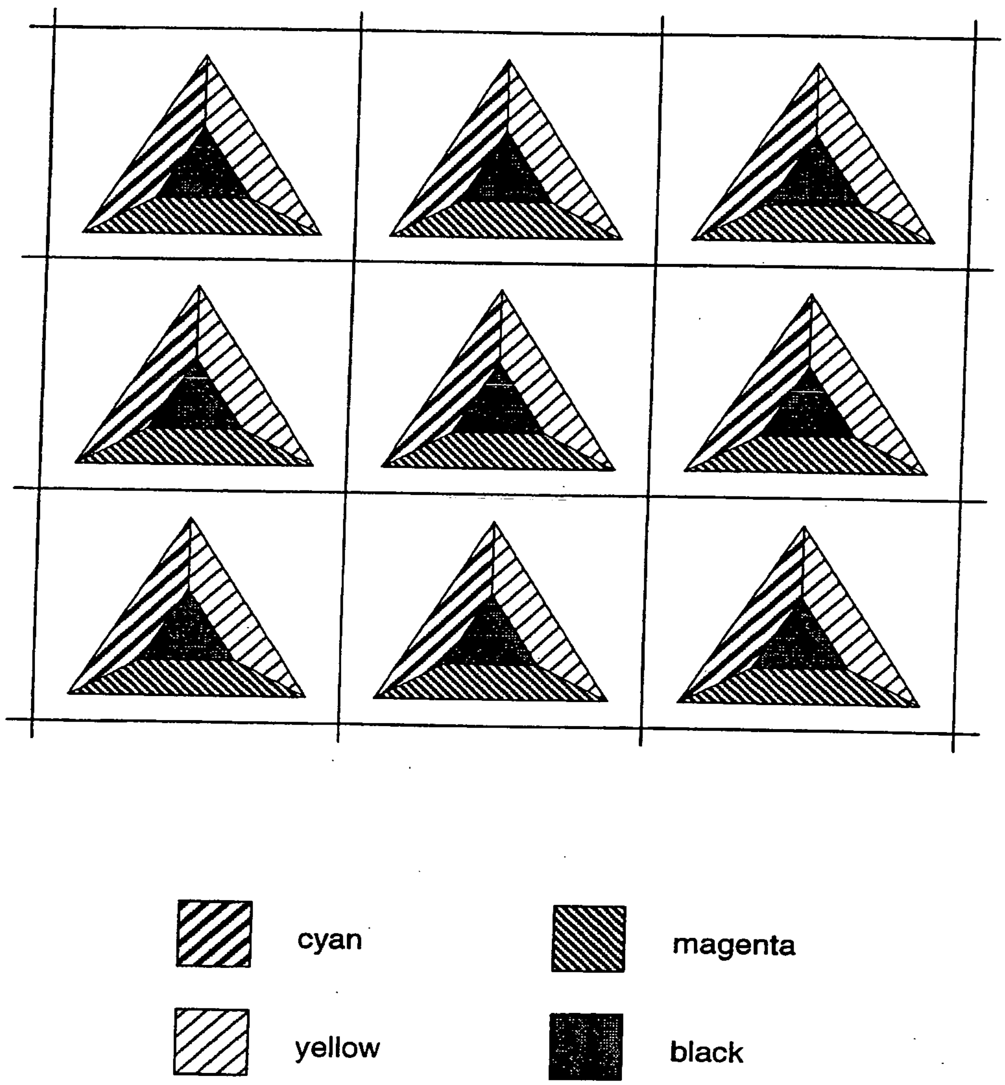


FIG. 14A

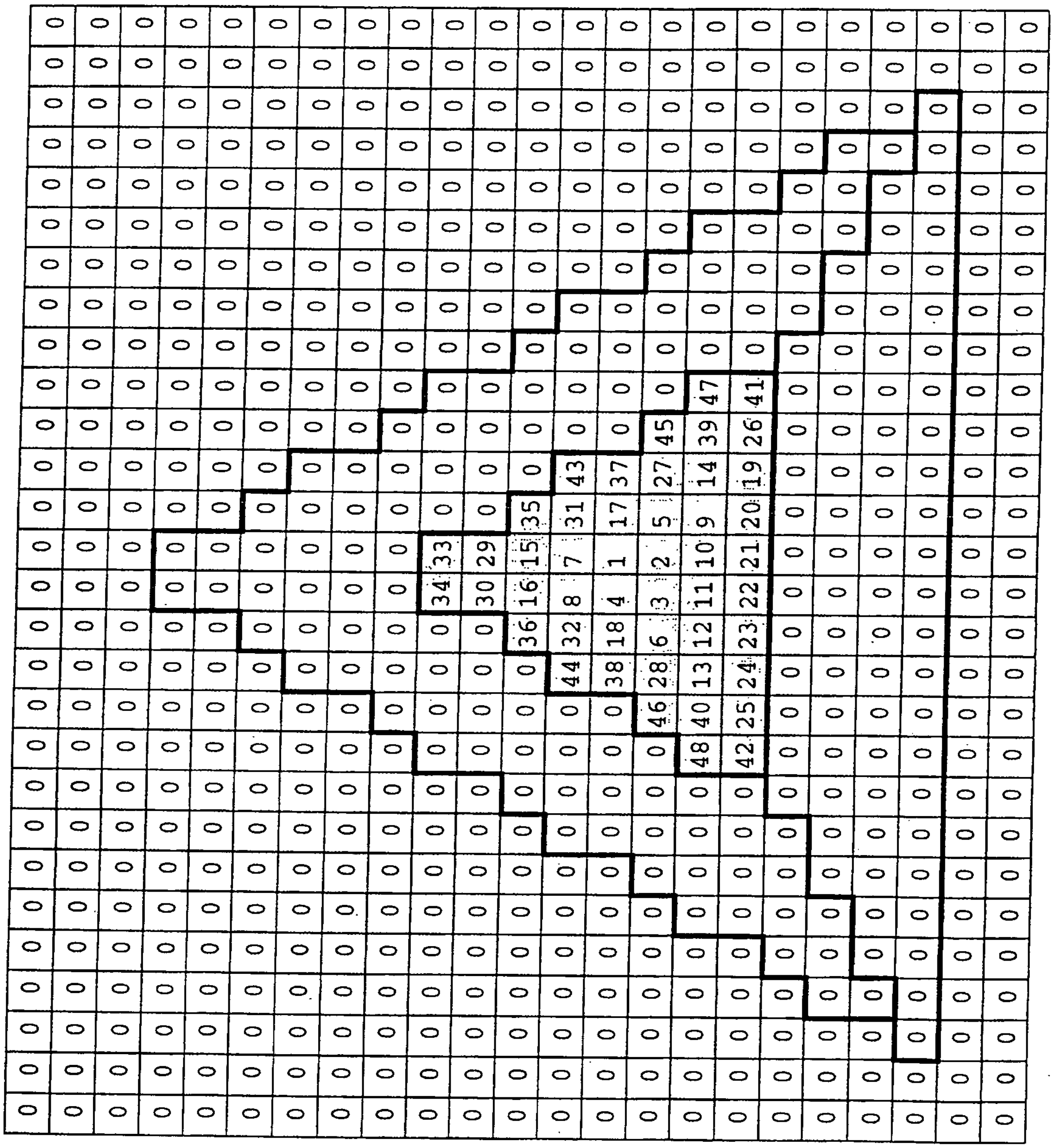


FIG. 14C

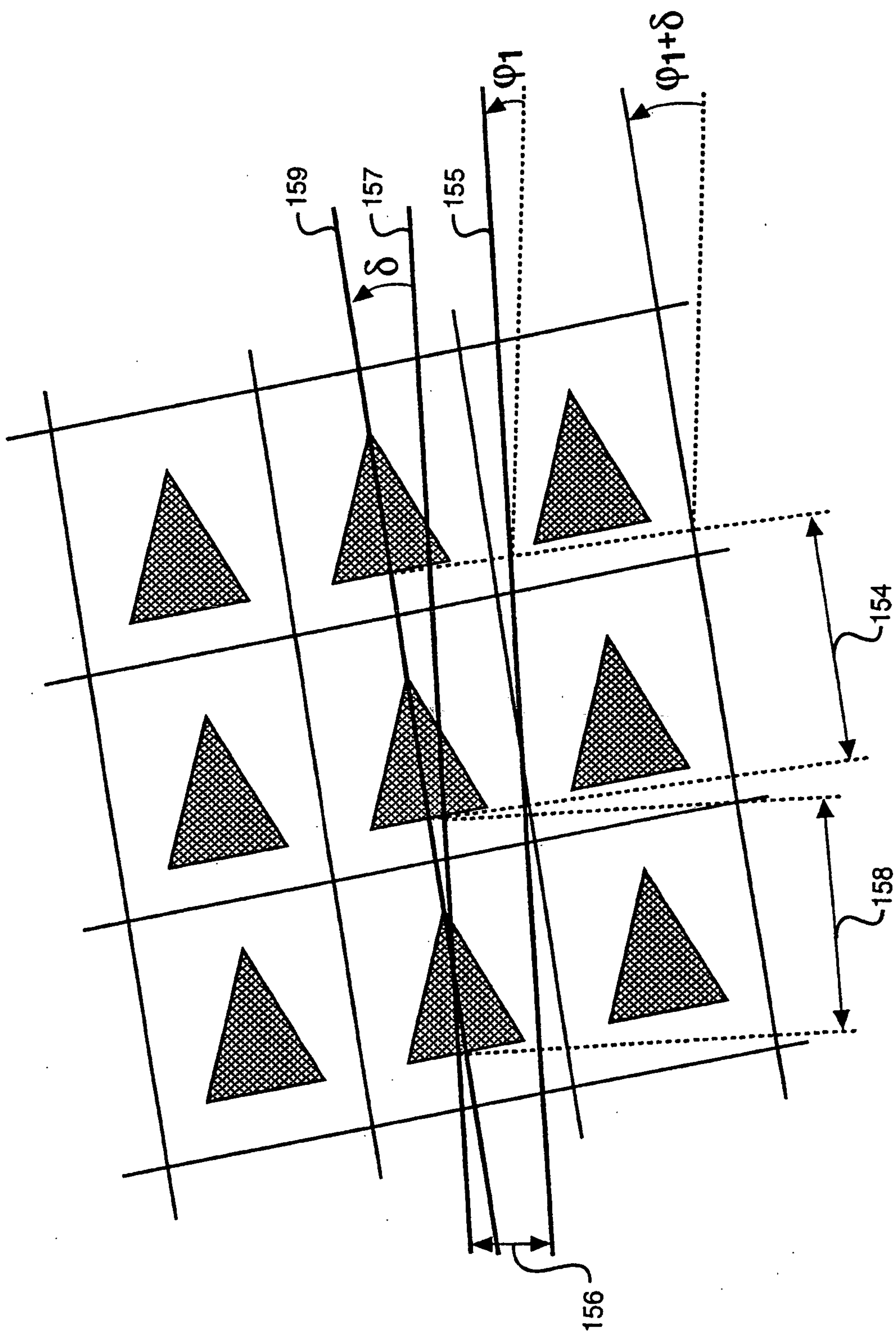
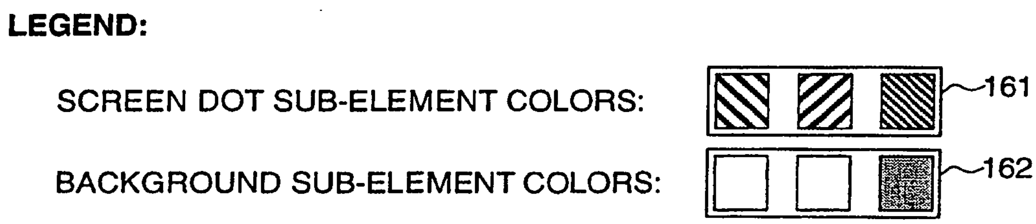


FIG. 15B



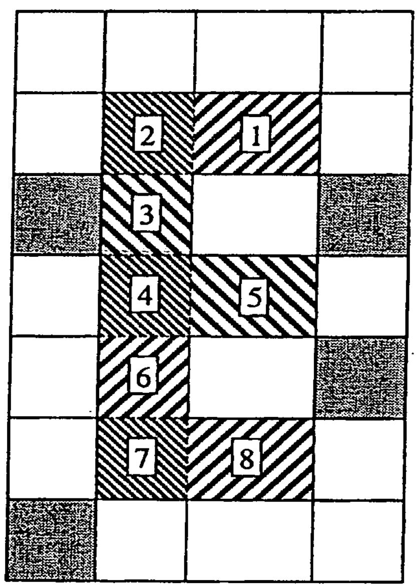


FIG. 16A

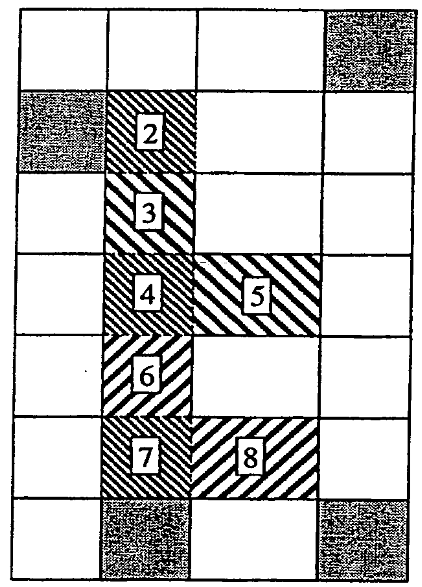


FIG. 16B

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IB 99/01895

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G07D7/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G07D B41M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 99 26793 A (HIBBERT CAMERON REX ;SECURENCY PTY LTD (AU); MELLETT LEE TASMAN (A) 3 June 1999 (1999-06-03) page 2, line 2 -page 3, line 7 claims	1,2,4,5, 8,21,23, 24
A	ZIENTEK P: "Polymeric self-authenticating banknotes" OPTICAL SECURITY AND COUNTERFEIT DETERRENCE TECHNIQUES II, SAN JOSE, CA, USA, 28-30 JAN. 1998, vol. 3314, pages 272-274, XP000925186 Proceedings of the SPIE - The International Society for Optical Engineering, 1998, SPIE-Int. Soc. Opt. Eng, USA ISSN: 0277-786X the whole document	1,4-6, 21-23

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 August 2000	09/08/2000
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Bocage, S

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